DEVINE MILLIMET

ATTORNEYS AT LAW

RECEIVED
CENTRAL FAX CENTER
APR - 2 2004

OFFICIAL

FAX COVERSHEET

Date: February 4, 2004

Number of Pages (Including Coversheet): 6

NAME	COMPANY	FAX NO.	PHONE NO.
Davienne Monbleau, Examiner	United States Patent and Trademark Office	703-872-9306	

From: Paul C. Remus

IF THERE IS A PROBLEM WITH THIS TRANSMISSION, OR IF YOU DID NOT RECEIVE ALL PAGES, PLEASE CALL:

Operator: Heather

Telephone: 603-669-1000

Comments: This fax will not be followed by mail.

Client/Matter No. 12679/59343

NOTICE

DEVINE, MILLIMET & BRANCH PROFESSIONAL ASSOCIATION
111 AMHERST STREET MANCHESTER NEW HAMPSHIRE 03101
T 603.669.1000
F 603.669.8547
DEVINEMILLIMET.COM
MANCHESTER, NH
ANDOVER, MA
CONCORD, NH
NORTH HAMPTON, NH

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant : Evan Chicklis
Serial No.: 09/841,727
Filed : 4/26/01
Title : EYESAFE Q-SWITCHED LASER

Art Unit : 2828
Examiner : Monbleau
Docket No.: 12679/59343

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

EXAMINER INTERVIEW REQUEST

Dear Sir:

I respectfully request a phone interview among the Examiner, Davienne Monbleau, one of the inventors and myself before formally responding to the Office Action sent on December 11, 2003. I enclose for Examiner Monbleau a brief description of resonantly pumped erbium lasers that we would like to discuss with Examiner Monbleau prior to filing my Response.

Examiner Monbleau is invited to call me, Paul C. Remus, at 603-695-8506 at his convenience to schedule the interview.

Respectfully Yours,

Paul C. Remus
Registration No. 37,221
Attorney For Applicant

Devine, Millimet & Branch, Professional Association
111 Amherst Street

Manchester, NH 03101

p. 603-695-8506
f. 603-669-1000

General Overview Of Resonantly Pumped Erbium and Comparison to Conventional Sensitized Erbium Lasers

An eyesafe erbium laser refers to one where the laser emission is from the first excited state ($^4I_{13/2}$) to the ground state ($^4I_{15/2}$). In general, this emission is found to be between 1.53 and 1.65microns, and is primarily driven by the host composition (i.e., silica glass, phosphate glass, YAG crystal, YLF crystal, etc.).

The technical approach we have laid forth in patent application number 09/841,727, titled Eyesafe Q-switched Laser, has numerous subtle differences from conventional technologies previously published or patented. To make this clear, we first briefly review the "conventional" way of making an eyesafe erbium laser.

Conventional Erbium Excitation Scenario

Until recently, there was no efficient way of exciting the upper laser state ($^4I_{13/2}$). Figure 1 shows how it was most commonly done. A sensitizing agent, most commonly trivalent ytterbium (Yb^{3+}) is the direct absorber of pump radiation. It is usually heavily doped into the host matrix to insure efficient pump absorption. The wavelength for pumping Yb^{3+} is usually between 940 and 980nm. The excited Yb^{3+} ions transfer energy by a radiationless process by exciting nearby trivalent erbium (Er^{3+}) ions into the $^4I_{11/2}$ level. These quickly decay into the $^4I_{13/2}$ level. The Er concentration is kept relatively low (<2% concentration) to optimize the transfer of energy from Yb to Er, and not the reverse process. An example of this type of laser system is described by Stultz et al in US Patent # 6,246,711.

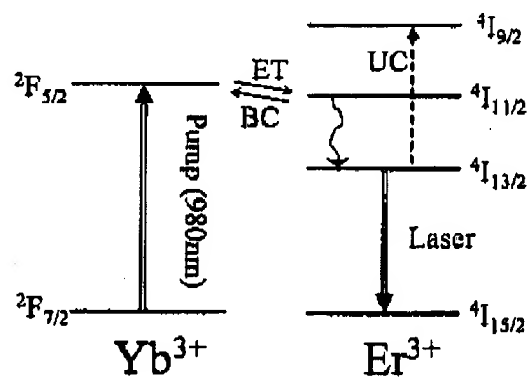

Figure 1. Traditional erbium excitation scenario using a Yb-sensitizer

There are some serious limitations to this architecture for eyesafe ($^4I_{13/2} \Rightarrow {}^4I_{15/2}$) laser extraction. First, the radiationless transition from the $^4I_{11/2}$ level to the $^4I_{13/2}$ level results in waste heat, and this makes high average power operation (with multi-Watt output) very difficult.[†] Another way of looking at this is considering the "quantum efficiency" of the system. At best, each pump photon will create one eyesafe laser photon, and the theoretical maximum efficiency is the ratio of photon energies

($\lambda_{Pump}/\lambda_{Laser}$ ~ 0.98/1.6 ~ 62%). The 40% of the pump power that doesn't result in laser action is primarily waste heat.

Another, more significant limitation is that of energy storage. The populations of the Yb and Er ions reach an equilibrium condition, in which only a small fraction of Er ions are populated. The vast majority of energy stored in the laser medium is held by the Yb ions. When one tries to rapidly extract the stored energy (by Q-switching), only the eyesafe energy held by the Er ions can be realized. This problem is well known to those skilled in the art of sensitized laser systems. Hence, not only are Yb-sensitized eyesafe erbium lasers poor high average power sources, they are inefficient Q-switched lasers.

As an analogy to this Er laser approach, our patent application discusses the more common systems of thulium-sensitized holmium (analogous to Yb-sensitized Er) resonantly pumped holmium (analogous to resonantly pumped Er, described next).

Resonant Pumped Scenario (Patent App. 09/841,727)

We have devised means of mitigating the above mentioned problems. They are quite unique in nature and significantly different than previous technologies. Key to our approach is the use of resonant pumping. Resonant pumping refers to direct excitation of the upper laser state ($^4I_{13/2}$ in this case). Figure 2 shows this scenario. A pump laser of appropriate wavelength directly excites the upper laser level, and no energy transfer process is required (though parasitic upconversion can still occur out of the $^4I_{13/2}$ level). The elimination of the sensitizing Yb ions provides two significant benefits. First, the elimination of the radiationless energy transfer from the $^4I_{11/2}$ to $^4I_{13/2}$ state eliminates a large amount of waste heat. In fact, in one embodiment of the invention, we pump at 1530nm, so the quantum efficiency is now ($\lambda_{Pump}/\lambda_{Laser}$ ~ 1.53/1.6) about 96%. In another embodiment we pump at 1470nm, so the quantum efficiency is still ($\lambda_{Pump}/\lambda_{Laser}$ ~ 1.47/1.6) about 92%. Hence high average power operation is possible without the thermal problems associated with the sensitized system.

The second great advantage of this approach is that all of the absorbed pump energy is stored by the Er ions, therefore all of it is available for Q-switched extraction, making this an efficient high-energy eyesafe laser system.

The primary difficult with operating the eyesafe erbium laser transition without a sensitizer is pump efficiency. We desire dilute (<2%) Er concentrations to minimize the effects of upconversion (a parasitic loss mechanism to upper lying Er levels, driven primarily by the concentration (i.e., physical proximity) of the excited Er ions). The peak absorption coefficient to the $^4I_{13/2}$ level from the ground state is relatively low (~0.85cm^{-1} at 0.5% doping level), so long crystals are required to efficiently absorb the pump (L = 4 – 6cm). Figure 3 shows the absorption spectrum of Er-doped YAG, one embodiment of this invention. Strong absorption features occur at ~1532nm, ideal for excitation with an Er fiber laser, or an erbium glass laser (both of these are of the traditional Yb-sensitized Er laser architecture). Absorption features near 1470nm can be excited with laser diodes. It is only with recent developments in 1470nm diode lasers and 1530nm fiber lasers that

the resonantly pumped eyesafe Er lasers (capable of high average power and high energy storage) could be developed.

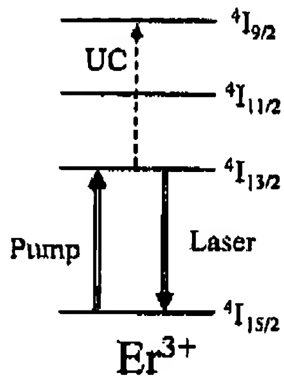

Figure 2. New erbium excitation scenario without Yb-sensitizer. This permits high power / high energy operation, enabled by newly available pump sources.

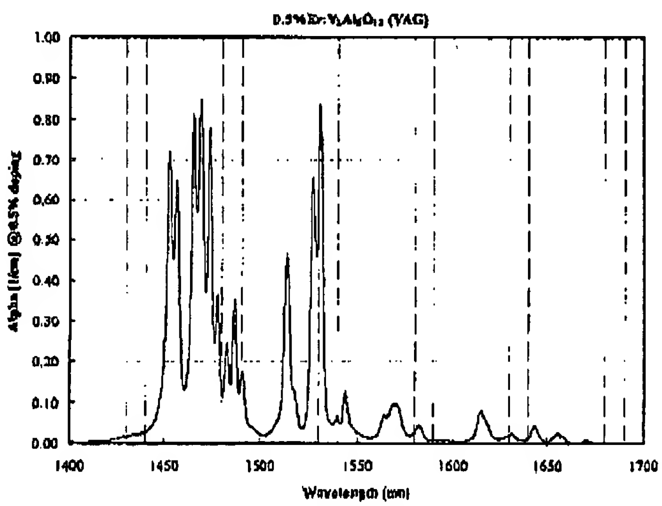

Figure 3. Example of erbium $^4I_{13/2}$ absorption spectrum (Er:YAG) showing peak absorption features near 1532nm (fiber laser pumping) and 1470nm (direct diode pumping).

<u>Summary</u>

While the specific laser transition in trivalent Er ($^4I_{13/2} \Rightarrow {}^4I_{15/2}$) and the concept of directly pumping the excited state of a lasing ion are both known to people skilled in the art, we believe we have developed an approach to making the eyesafe Er laser efficiently operate at high average power and/or high Q-switched pulse energy. We have solved the problems typically associated with eyesafe Er lasers (high heat load, poor energy storage, poor absorption efficiency) by the processes of resonant pumping *of the first excited state*, by *eliminating the sensitizers*, and by reducing upconversion losses with *dilute Er concentrations*.

[1]The one notable exception to this is the erbium fiber laser. It operates on this same principles described here (i.e., Yb-sensitization), but the fiber medium permits the heat load to be distributed over very large surface area, permitting high average output powers.

However, the very mechanism that makes it work preclude high Q-switched energy output. Aside from other limiting issues described above, since all of the laser energy is confined to a very small area in the core of the fiber, Q-switching to generate energetic pulses results in very high fluences that damage the fiber. To date, the highest energies obtained from this approach have been on the order of 1mJ. Additionally, the very long cavity length formed by the fiber make short pulse generation (<50ns) from the Q-switching process impossible.

[ii]Note that resonant pumping itself is not new, nor is resonant pumping of erbium. For example, Er^{3+} has a well-known laser transition from 4I11/2 to 4I13/2, emitting around 2.8microns. Esterowitz et al refer to this process in patent number 5,200,966, titled Resonantly pumped, erbium-doped, GSGG, 2.8micron, solid state laser with energy recycling and high slope efficiency. They resonantly pump the 4I11/2 state, whereas we resonantly pump the 4I13/2 state. The 2.8micron emission is not in the conventional "eyesafe" window around 1.5 – 1.6microns, and the laser dynamics are entirely different than our approach. Energy cannot be stored efficiently, and they rely on relatively large (20 – 50% concentration) whereas we prefer to keep the concentration <2% to reduce upconversion effects. While Kokubu refers to this ~2.8micron laser, as well as the traditional eyesafe erbium laser, in patent number 6,179,830, titled Laser Probe, he does not disclose any means of improving the traditional eyesafe laser performance (as we have in our application).